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James Gamble

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The purpose of the study was to determine if the multispectral method of remotely discriminating natural materials had practical application for highway and environmental planning, and for route selection. At the present stage of development the method does not obviate aerial photography and field studies to obtain the information of engineering significance required for preconstruction planning.

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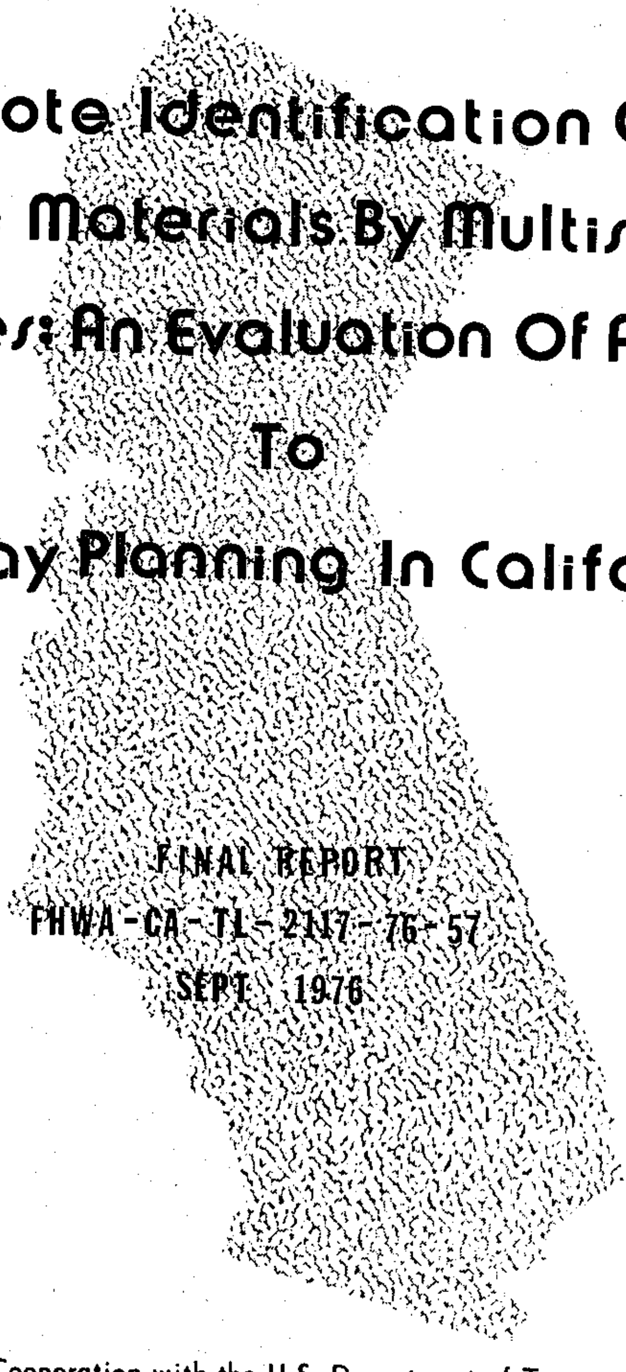
DIVISION OF STRUCTURES AND ENGINEERING SERVICES

TRANSPORTATION LABORATORY

RESEARCH REPORT

Remote Identification Of Geologic Materials By Multispectral Techniques: An Evaluation Of Applicability To Highway Planning In California



FINAL REPORT

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CALIFORNIA DEPARTMENT OF TRANSPORTATION

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DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

September 1976

TL No. 632117
FHWA No. G-2-3

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

REMOTE IDENTIFICATION OF GEOLOGIC MATERIALS BY MULTISPECTRAL TECHNIQUES: AN EVALUATION OF APPLICABILITY TO HIGHWAY PLANNING IN CALIFORNIA

Study made by . . . . Geotechnical Branch

Under the Supervision of . . . . R. A. Forsyth

Principal Investigator . . . . M. L. McCauley

Co-Investigator . . . . James Gamble

Report Prepared by . . . . James Gamble

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

JG:lb

ACKNOWLEDGEMENTS

At the Transportation Laboratory, Mr. Colin Love was the first investigator on this project. He wrote the proposal in April, 1972 and subsequently aided in the site selection. During the summer months of 1972 preceding the data collection flights Mr. Ron Mearns was in charge of the project at the Laboratory and acted as coordinator with the other agencies. Following the collection of data in late September 1972, Mr. Harold Eagle had primary responsibility for the project, and together with the author did the geologic mapping. After leaving the project in August, 1975 he made many suggestions that were helpful in preparing this report.

TABLE OF CONTENTS

INTRODUCTION

This report evaluates the results obtained at a California test site by a study to develop techniques for automatically identifying terrain features and natural materials by remotely sensed multispectral imagery. Test sites in Pennsylvania, Kansas, and Virginia were also investigated in a cooperative effort involving the Federal Highway Administration, the State Highway Departments, and the Environmental Research Institute of Michigan (ERIM). The studies were directed by Dr. Harold Ribb of FHWA; the state agencies selected the sites and provided ground observations for the remote sensing flights by ERIM. The data was processed and analyzed at the ERIM facilities. In Califonia, geologists at the Transportation Laboratory selected the test site and made a detailed geologic map to provide accurate ground truth of the study area.

The multispectral scanner (MSS) data was collected over the Halloran Springs, California test site September 30, 1972. The data was subsequently processed by ERIM and the Laboratory for Applications of Remote Sensing at Purdue University (LARS). Each laboratory used a separate process to test their ability to correctly identify and delineate the geologic materials at the test site.

The investigative techniques used, and the degree of success achieved, is described in the following three reports:

1. The Remote Identification of Terrain Features and Materials at a California Test Site: An Investigative Study of Techniques: ERIM Interim Report, April 1974. Report No. FHWA-RD-74-27.

2. Investigation of Multispectral Techniques for Remotely Identifying Terrain Features and Natural Materials: ERIM Final Report, May 1974. Report No. FHWA-RD-74-28.

3. Analysis of Multispectral Data Using Computer Techniques: California Test Site. Draft Copy, 1976, LARS, Purdue University.

The LARS final report was delayed and consequently this report evaluates only the ERIM results.

The purpose of the study described in this report is to evaluate, from the perspective of personnel experienced in highway planning and construction, the accuracy and general usefulness of the processed remotely sensed data for highway location and design. To make this evaluation, the processed multispectural data depicting the various geologic materials at the Halloran Springs site is compared directly with the geologic map prepared by geologists at the California Transportation Laboratory. This map served as ground truth for both this report and the ERIM Studies. Also, the conclusions of the authors of the three previously published reports are carefully considered. It is noted, however, that the conclusions in the LARS report are partly based on a modified and more generalized ground truth geologic map than that prepared at the Transportation Laboratory.

The ERIM final report concludes that "developed techniques for collection and processing of multispectral scanner data are useful in the delineation of terrain features, such as soil and geologic materials, water bodies, and vegetation types. Detailed soil mapping by computer processing of multispectral data is generally feasible, but probably practical only in level areas largely free of vegetative cover".

The conclusions from the LARS investigation on the general application of remote sensing to highway location, design, and construction are that computer-aided classification of multispectral sensor data is useful in determining surface materials, but that even under ideal conditions an accurate, detailed materials map is difficult to obtain without input from photo interpretation and ground observations. The authors of the LARS report found that landform identification by computer-assisted MSS analysis at the Halloran Springs test site was no better than evaluations that could have been made using color and color IR photography. They concluded that a combination of interpretation of black and white photos plus interpretation of MSS computer-assisted classifications could yield a reasonably accurate materials map at the test site.

The authors of this report consider it important to reiterate that remotely sensed multispectral classifications do not, at their present stage of development, replace the need for field study if detailed information is required.

Vegetation is very sparse at the Halloran Springs test site, but was sufficiently dense in the higher eastern part of the test area to mask the natural materials and thus significantly lower the classification accuracy of both the ERIM and LARS data processing techniques.

The present status of multispectral remote sensing as a method of geological mapping and materials classification is concisely stated in the preface of the final ERIM report: "Much more development in multispectral techniques needs to be done before practical applications are economically feasible." After careful evaluation of the material classifications obtained from the remotely sensed multispectral data, participants in the study at the Transportation Laboratory concur.

CONCLUSIONS

Multispectral techniques for remotely identifying terrain features and natural materials, at the present stage of development, cannot, independent of the methods now used, yield a sufficient amount of information to enable transportation planners to select with confidence one of several alternative corridors. Selection would be increasingly difficult in areas having more than a sparse growth of vegetation. Judgmental decisions on slope stability, strike and dip of bedding planes, fracture patterns, degree of weathering, durability of rock units, drainage, geologic hazards, etc., cannot now be made from the processed data output obtained by airborne multispectral scanners. With much more development in multispectral techniques, applications for highway planning may become practical and economically feasible.

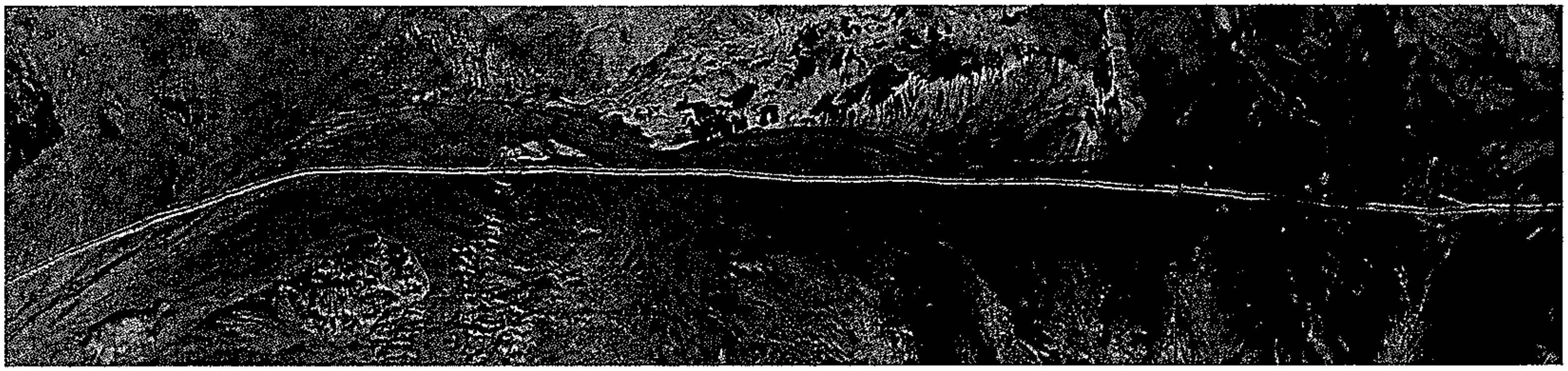
RECOMMENDATIONS

A recommendation for implementation is not warranted at the present time. However, cooperative efforts with ERIM, LARS, or other qualified research institutions in future investigations aimed at perfecting the multispectral technique should be encouraged. The Department of Transportation would thereby keep informed of new developments in a rapidly advancing field that has potential for becoming operational as a new method of obtaining remotely sensed geologic, engineering, and environmental data.

IMPLEMENTATION

The multispectral technique for remotely identifying terrain features and materials, i.e., geologic mapping, is not considered practical or economically feasible for highway planning in California at the present time. The stereoscopic views and high resolution afforded by aerial photography, in both black and white and color, obtainable and processable at relatively low cost, places stringent requirements on the degree of perfection and availability the multispectral technique must attain to displace aerial photography as the remote sensing technique most useful for engineering purposes. While awaiting further development, the method can provide, in sparsely vegetated areas, compositional information of the natural materials as a useful supplement to aerial photography.

Although no recommendations for implementation are made in this report, the results obtained from the investigation by ERIM and LARS are impressive. Geological personnel of the Transportation Laboratory should keep informed of new developments in multispectral scanning and processing techniques.



North

FIGURE 1. COLOR COMPOSITE OF RATIOS $R_{2,1}$, $R_{9,5}$, AND $R_{12,11}$ FOR HALLORAN SPRINGS TEST SITE, 1828.7-m ALTITUDE

(After Vincent, Dillman, and Hasell, April, 1974)

TABLE 1. CANDIDATES FOR SCENE MATERIALS IN THE HALLORAN SPRINGS COLOR-CODED RATIO MAP, BASED ON LABORATORY SPECTRA OF ROCKS AND MINERALS

Color	Rocks and Minerals
Red	Hematite, Hematitic Basalt (and probably mafic dikes)
Red-Orange	Hornblende Granite, Biotite Granite, Hornblende Diorite
Orange (dark)	Quartz
Yellow-Orange (light)	Andesite Porphyry
Yellow	Gypsum (Italy), Leuco-Granite (and probably pegmatite dikes)
White	Fresh Basalt
Yellow-Green	Leuco-Granite, Sandstone Conglomerate (and probably young alluvium)
Green	Gypsum (Utah), Fresh Monzonite, Syenite
Blue-Green	Montmorillonite, Kaolinite
Blue	Limestone, Calcined Basalt
Mauve	Pyrite
Purple	Limonite, Goethite, Coarse Grass (and probably old alluvium)
Purple-Brown	Gneiss, Biotite, Pumice, Dry Mud
Brown	Chert
Brown-Black	Sand, Windhorst Type (Oklahoma) (and probably stream channels)

(After Vincent, Dillman, and Hasell, April 1974)

TEST SITE

Geologic Mapping

The Halloran Springs test site is located in San Bernardino County 10 miles east of Baker on Highway 91 in the Mojave Desert region of southeastern California. The site, six miles long by two miles wide, was selected by Transportation Laboratory geologists because of the sparse vegetation, variety of well-exposed bedrock and alluvial materials, and absence of atmospheric haze and smoke in this high desert location.

Previous geologic mapping of this area by Hewett (2) and by Moyle (4), was considered too generalized for the purpose of the multi-spectral investigation and it was decided to map the area in detail on a five-foot contour base map prepared by the Department of Transportation. The geologic mapping was done during the periods of November 13 to 23 and December 4 through 12, 1972, by two geologists from the Transportation Laboratory. The resulting geologic map is shown as Figure 5.

In late September, 1972, prior to the geologic mapping, personnel from the geotechnical group at the Transportation Laboratory met with Mr. James F. Koca, FHWA, Dr. Terry West from Purdue University, and Mr. Tom Wagner from the Environmental Research Institute of Michigan, to aid in marking the boundaries of the test site, selecting and photographing training sets, collecting and describing typical samples of each rock type, and to provide transportation in the field.

Geology

Briefly, the geology of the test site consists of low, resistant bedrock hills of Precambrian gneiss, Tertiary quartz monzonite, a coarse-grained, reddish-colored Tertiary sandstone, and Pleistocene basalt flows. Other bedrock types that have relatively small areas of outcrop are migmatite, carbonate rock, a coarse angular grit or pebble conglomerate, undifferentiated sedimentary rocks, andesite, and basic and siliceous dikes. Between these bedrock exposures are alluvial fans, terraces, and washes composed of mechanically weathered debris from the bedrock material. The surface area is about equally divided between bedrock exposures and alluvial deposits. In many areas there is no clear demarkation between quartz monzonite bedrock and the coarse alluvial material (Qsf) accumulating from mechanical disintegration of the parent rock. This is especially true on the moderately steep slopes that are characteristic of the terrain in the south half of the test area. The basalt flows that are so conspicuous in the north half of the area are comprised of black vesicular basalt that in gross aspect tends to be blocky. The basalt flowed out over an erosion surface on the quartz monzonite that was, in part, thinly covered by alluvium. The LARS report notes that patches of white tuff cap the basalt. The tuff deposits were not observed during the geologic mapping. However, at the time the basalt was mapped the area was covered by snow. The early Precambrian gneiss is comprised of mottled dark and light colored, hard, closely fractured rocks that, during or prior to metamorphism, were thoroughly permeated by both basic and siliceous dikes.

Fortunately the success of the investigation was not directly dependent on detailed knowledge of the geologic structure; it is believed to be much more complex than is shown on the geologic map. Hewett (2) mapped a northeast trending fault along the wash followed by the highway through the test site, and a northwest trending fault along the eastern edge of the basalt flow. The faults in the northeastern corner of the test site, and also those south of the highway were mapped during the present field study.

Collection of Data

The multispectral scanner data were collected over the Halloran Springs, California, test site in the fall of 1972. This time period was planned to coincide with Earth Resources Technology Satellite (ERTS) coverage of the test site. Flights at two altitudes, 3,000 and 6,000 feet during both daylight and predawn were flown in clear weather on September 30, and October 1, 1972 respectively. Multiple bands of thermal imagery were obtained during both the daylight and predawn flights, and other spectral bands and various aerial camera film/filter combinations were registered during the midday flights.

A detailed description of the airborne sensors and the specific configuration used to collect the multispectral data is given in the ERIM interim report (5) and in the LARS (3) report. The complex data processing techniques are also described in the aforementioned reports and are not treated herein.

Described very briefly, the remotely sensed data was obtained by an M7 multispectral scanner mounted in the ERIM C-47 aircraft. Twelve spectral bands in UV, Visible, and IR regions form a continuous strip image of the terrain beneath the aircraft. Terrain radiation is registered by radiation detectors; the electrical outputs of the detectors are amplified and recorded on analog magnetic tape. Nineteen spectral bands over a wavelength range of 0.33 to 14.0 μm can be generated by the scanner system. At any one time twelve of these bands are selected for tape recording on a 14-track analog tape machine. An array of aerial cameras utilizing three film/filter combinations produce film records used in the analysis of the scanner data. The M7 scanner system is experimental and is continually being changed to improve its performance. Its first use was over the Halloran Springs test site.

CLASSIFICATION EVALUATION

Our evaluation of the rock classification accuracy for the three methods of processing the multispectral data was limited to visual comparison of the classification strip maps shown in Figures 2, 3, and 4 of the ERIM interim report (5), with the geologic map. These figures were reproduced and are also shown in this report as Figures 2, 3, and 4. The ERIM classification strip maps and a reduced copy of the geologic map were divided into 16 equal-sized rectangular "sections" by grids drawn on each figure. The "sections" were numbered as shown in Figure 2(a) to facilitate reference to a particular location.

We realize that this method of analysis has an element of subjectivity and does not yield statistical or percentage values. Such a method was necessary, however, because of the great discrepancy in scale between the strip maps and the reduced geologic maps. The method does have the advantage of the viewer evaluating the entire scene rather than comparing classifications at point locations selected at random.

The only other material available for study was a color composite (Figure 1) made from the three most important ratio images that were color-coded cyan, magenta, and yellow. The area of the strip maps and the color composite extend for considerable distances beyond the east-west boundaries of the geologic map.

ERIM researchers evaluated the classification accuracy by drawing a grid on the ground truth map and adding a matching grid to the ratio color composite, RAGAL, and Euclidian distance classifications.

Grid intersections were selected at random and the classification of material at these points was compared to ground truth. The results of this analysis were shown in Tables 7 and 8 of the ERIM final report. Permission was obtained for use of these tables in this report where they are reproduced as Tables 2 and 3.

Nineteen units are differentiated on the geologic map used for ground truth but only seven are specific rock types; eight are different depositional forms, two are dikes, one the mixed rocks of a contact metamorphic zone, and one is undifferentiated sedimentary rocks. ERIM classification by processed multispectral data is concentrated primarily on recognizing compositional differences (rock types). Therefore, the weathering products (alluvium in any depositional form) from a single rock type are generally not differentiated from the outcrop; mixed alluvial materials are equally difficult to identify. Although vegetation is sparse at the test site it was sufficiently dense in many cases, especially in the higher eastern part, to mask rock composition.

The three methods of multispectral data processing used by the ERIM researchers and described in their final report (1) are a color composite in which ratio images of the three optimal spectral ratios are color-coded, and a color composite then made; RAGAL that accomplished scene classification by using laboratory ratio values for seven materials and only one known area on the ground, and for four materials by using in-scene training sets; and euclidian distance classifications using in-scene training sets. Using these materials the spectral analysis and recognition was trained and produced the classifications presented in the ERIM interim report.

TABLE 2. ROCK CLASSIFICATION ACCURACY, IN PERCENT, FOR EACH OF THREE PROCESSING METHODS. Halloran Springs, California Test Site. Ground truth based on geologic map prepared by California Division of Highways.

Classification by Ground Truth	Method	Classification by Remote Sensing: Qb	$p\epsilon g$	ktm	Ts	Qsf	Qof and Qaℓ	Unclassified
Qb (Basalt)	1*	100					0	—
	2	50					50.0	—
	3	75					—	25.0
$p\epsilon g$ (Gneiss/ Granite)	1		83.3			16.7	—	—
	2		100.0			—	—	—
	3		33.3			—	8.3	58.3
ktm (Quartz Monzonite)	1	6.3 (13.3)†		21.9 (53.9)†	—	18.8 (40.0)†	53.2 (0)†	—
	2	—		—	—	—	—	—
	3	15.6		—	6.3	9.4	28.1	40.6
Ts (Tertiary Sandstone)	1	25.0			75.0		—	
	2	—			—		—	
	3	—			75.0		25.0	
Qsf (Slope Wash, Alluvial Fans)	1		—		—	54.8 (100.0)†	45.2	—
	2		—		—	—	—	—
	3		3.1		18.8	18.8	25.0	34.4
Qof and Qaℓ (Alluvium)	1					80.0	20.0	—
	2					38.2	—	61.8
	3					22.2	11.1	66.7

*KEY: 1 - Ratio Color Composite (calcium carbonate area used for normalization)
2 - RAGAL
3 - Euclidian Distance Rule

†Numbers in parentheses are accuracy estimates of non-vegetated sites. (The other numbers are accuracy estimates for both vegetated and non-vegetated sites.)

(After Hasell, May 1974)

TABLE 3. AVERAGE ROCK CLASSIFICATION ACCURACY FOR THE THREE METHODS USED IN PROCESSING HALLORAN SPRINGS, CALIFORNIA, MULTISPECTRAL DATA.*

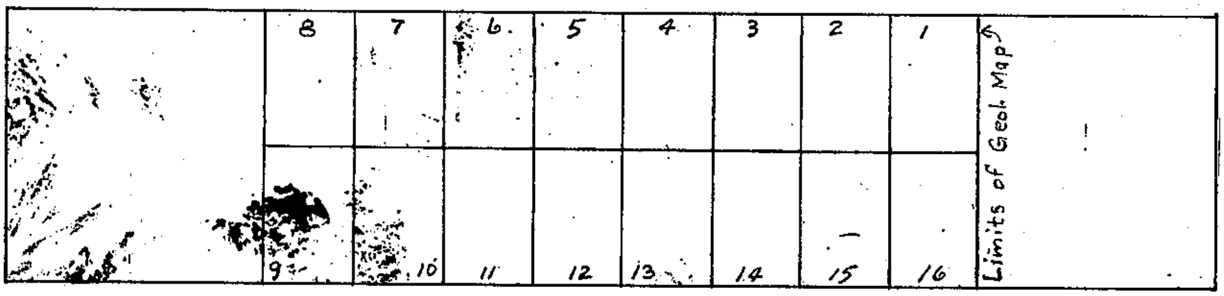
Method	Correct (%)	Commission	Omission
Color Composite of Selected Ratios (related to library ratio values and colors)	53.0 (77.9)†	47.0 (22.1)†	0
RAGAL (library spectra used for processor training)	43.9	0	36.1
Euclidian Distance Rule (in-scene spectra used for training)	37.0	24.0	39.0

*MS data for RAGAL processing collected at 3000 ft (914.7 m) altitude; other MS data collected at 6000 ft (1828.4 m).

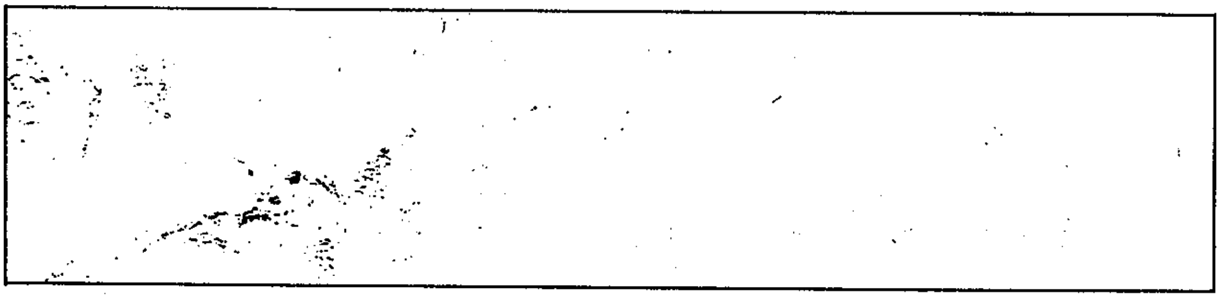
†Parenthesized percent figures indicate results after corrections for vegetation effects.

(After Hasell, May 1974)

In-scene training sets are small delineated areas of known rock type in the flight path used to train the computer from the characterizing terrain radiation received by the airborne scanner.



(a) Granite I



(b) Granite II

(c) Basalt I

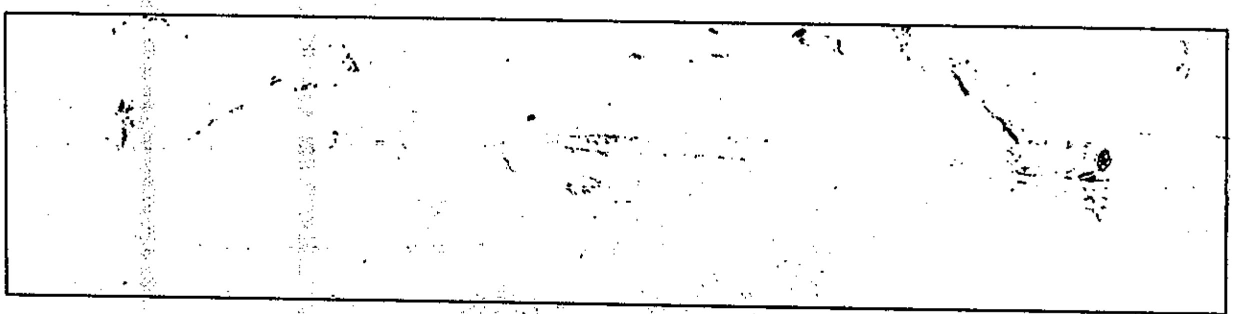
(d) Alluvium I

North

FIGURE 2. EUCLIDIAN DISTANCE CLASSIFICATION RESULTS, USING IN-SCENE TRAINING SETS, FOR HALLORAN SPRINGS TEST SITE, 1828.7-m ALTITUDE

(After Vincent, Dillman, and Hasell, April 1974)

(e) Sandstone Conglomerate



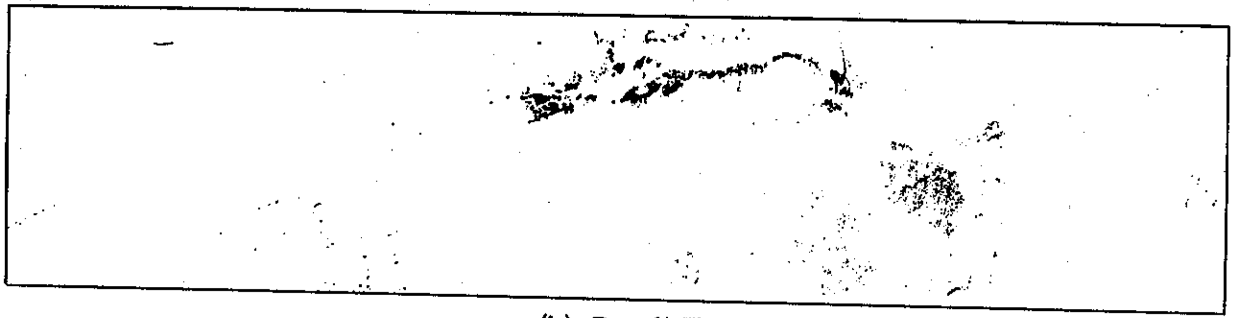
(f) Limestone

(g) Alluvium II

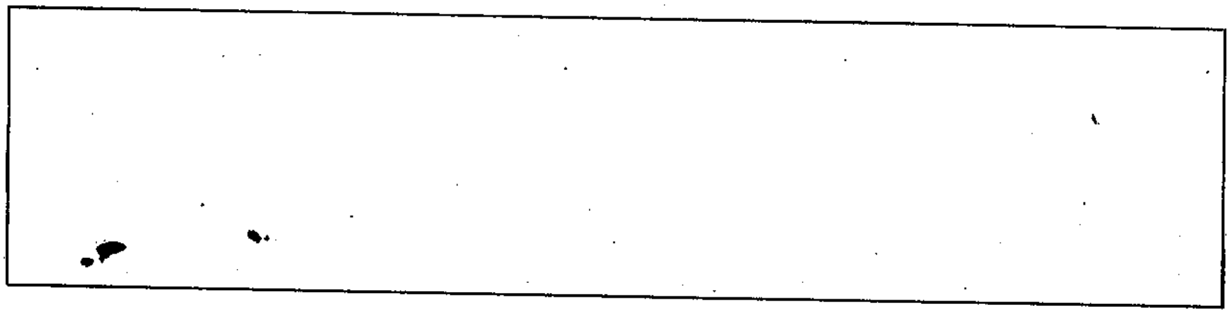
North

FIGURE 2. EUCLIDIAN DISTANCE CLASSIFICATION RESULTS, USING IN-SCENE TRAINING SETS, FOR HALLORAN SPRINGS TEST SITE, 1828.7-m ALTITUDE (Continued)

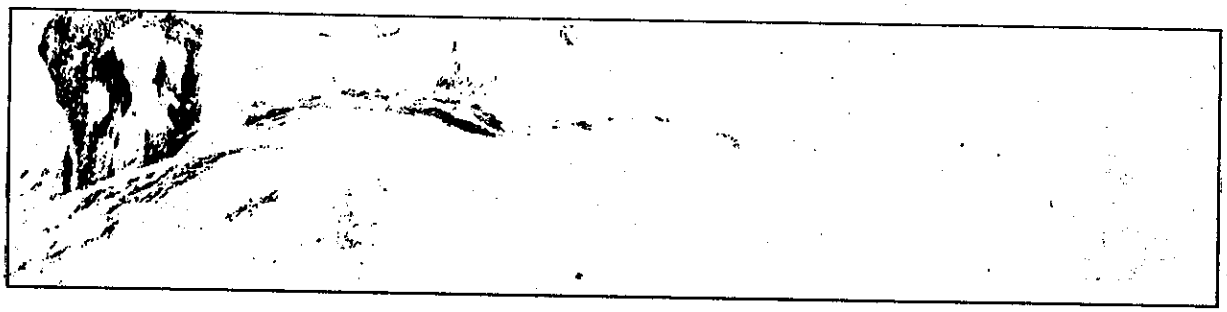
(After Vincent, Dillman, and Hasell, April 1974)



(h) Basalt II



(i) Granite III

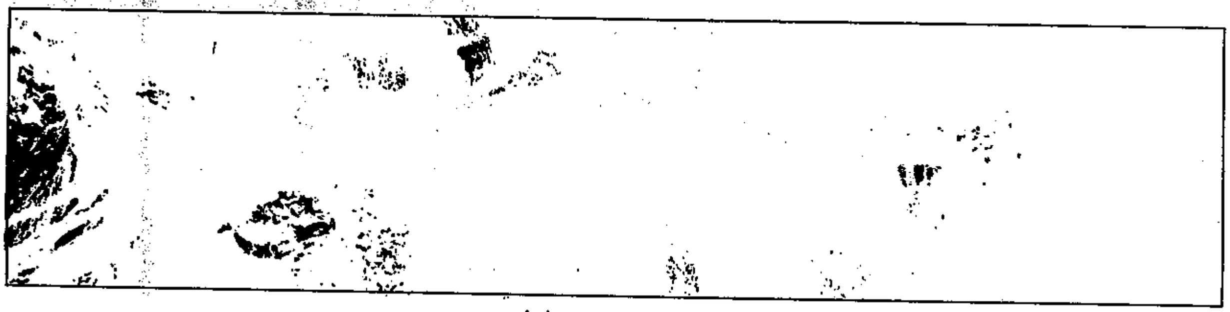


(j) Alluvium III

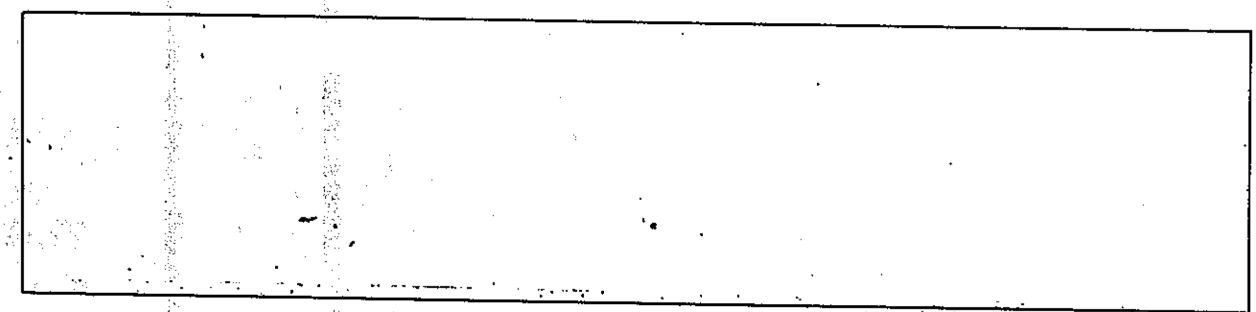
North

FIGURE 2. EUCLIDIAN DISTANCE CLASSIFICATION RESULTS, USING IN-SCENE TRAINING SETS, FOR HALLORAN SPRINGS TEST SITE, 1828.7-m ALTITUDE (Continued)

(After Vincent, Dillman, and Hasell, April 1974)



(k) Granite IV



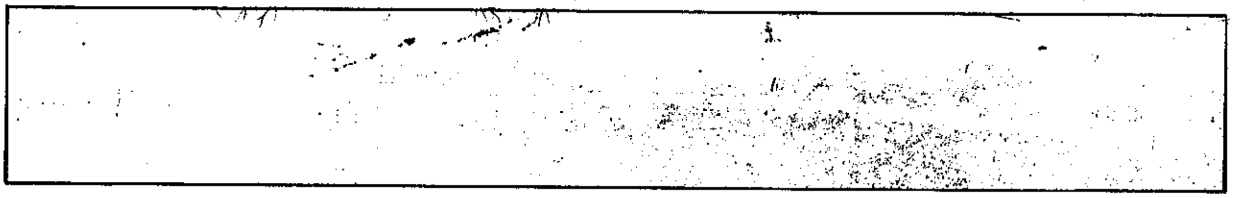
(l) Granite V

(m) Alluvium IV

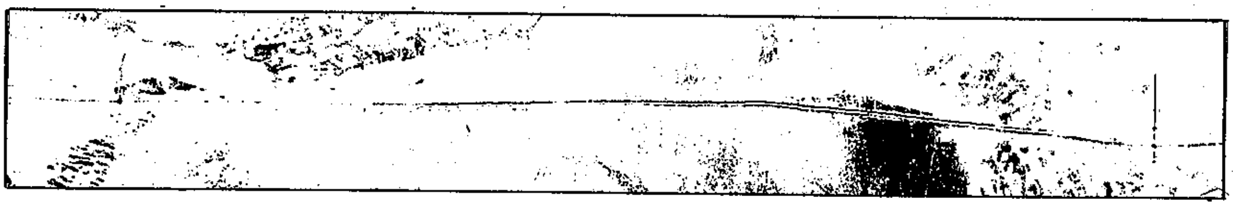
North

FIGURE 2. EUCLIDIAN DISTANCE CLASSIFICATION RESULTS, USING IN-SCENE TRAINING SETS, FOR HALLORAN SPRINGS TEST SITE, 1828.7-m ALTITUDE (Concluded)

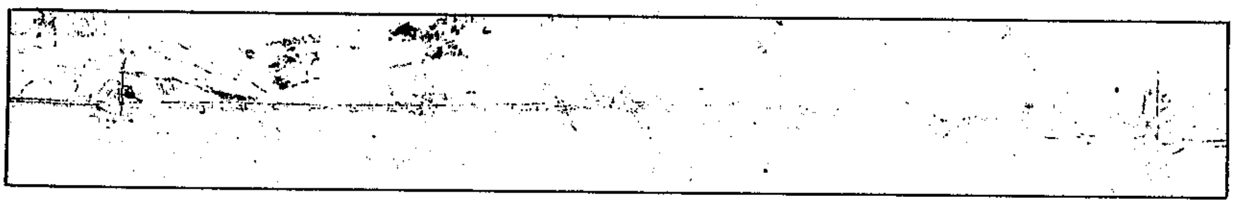
(After Vincent, Dillman, and Hasell, April 1974)



(a) Hematite



(b) Calcine-Coated Basalt

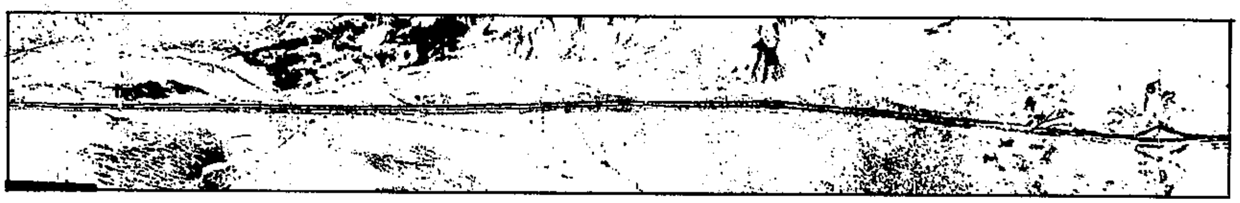


(c) Unweathered Basalt

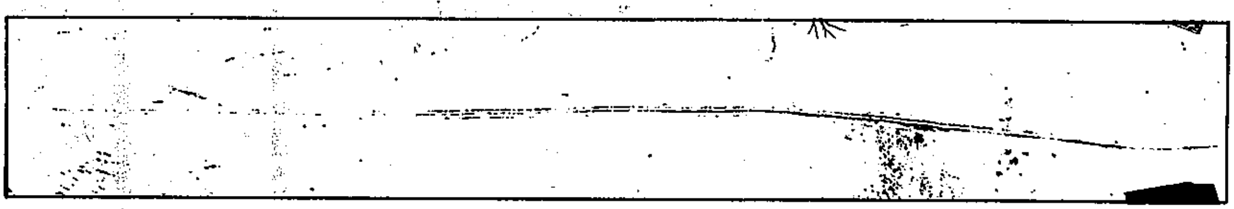
North

FIGURE 3. RAGAL CLASSIFICATION FOR THREE MATERIALS BASED ON LABORATORY RATIO VALUES USED FOR TRAINING, 914.4-m ALTITUDE
(After Vincent, Dillman, and Hasell, April 1974)

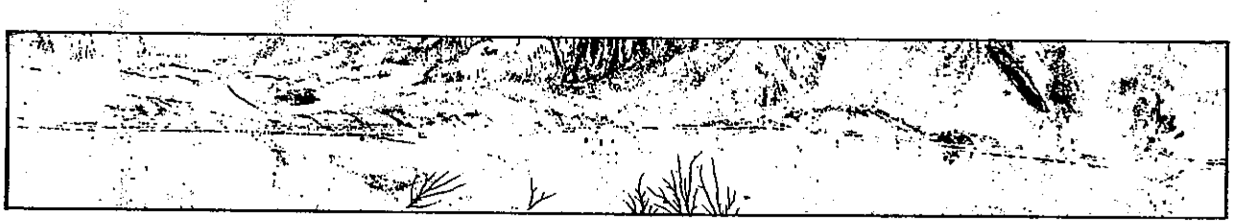
(a) Hematitic Basalt



(b) Unweathered Basalt



(c) Asphalt Road



(d) Limestone

North

FIGURE 4. RAGAL CLASSIFICATION FOR FOUR MATERIALS BASED ON IN-SCENE TRAINING SETS, 914.4-m ALTITUDE

(After Vincent, Dillman, and Hasell, April 1974)

Granite I, Figure 2(a) - The corresponding rock unit on the geologic map is Precambrian granite and gneiss that is well-exposed in two separate areas - "sections" 9 and 10 south of the highway and in "sections" 7 and 8 north of the highway. It is important to note that the gneissic rocks in these two areas are quite dissimiliar, those north of the highway being thoroughly injected by felsic intrusions. Multispectral representation of this large outcrop area of injected gneiss is depicted only by minute scattered areas in "section" 7. The representation of the gneiss outcrop areas south of the highway is moderately good. The scattered representation shown in the south 1/2 of "sections" 7 and 13 and in the northwest 1/4 of "section" 6 is erroneous.

Granite II, Figure 2(b) - The ground truth rock type corresponding to Granite II is quartz monzonite. This geologic rock unit crops out over large areas south of the highway, and to the north in the eastern half of the test area. The representation of this areally extensive rock type is practically nil. All of the representation shown in "section" 9 is incorrect, and likewise most of that in "section" 10.

Basalt I, Figure 2(c) - Except for two small outcrops, basalt occurs only north of the highway where these volcanic flow rocks are the most prominently exposed in-place rock unit. The representation shown south of the highway ("sections" 14, 15, 16), and in "section" 1 north of the highway is incorrect classification. The basalt classification in the south 1/2 of "section" 13 includes a small area of basic intrusive rock; however, the area classified as basalt is too extensive and includes more quartz monzonite than basic intrusive rock. In "sections" 2, 3, 4, and 5, the top of the basalt flow is not classified; the basalt classification is for steeply sloping areas of quartz monzonite partly concealed by colluvium derived from the overlying basalt flow. There is no basalt in-place in the northwest 1/4 of "section" 5 or north 1/2 of "section" 6. The author recalls that basalt float may be extensive in these areas, a probable explanation for the apparent incorrect classification. The register of the two outcrop areas in the south 1/2 of "section" 7 is very good.

The ability to distinguish between bedrock and alluvial materials is of fundamental importance to highway engineering. As exampled by the basalt classification, remotely sensed multispectral data cannot at present always make this discrimination. On the color composite the greater part of the basalt flow, and the talus on the slopes below, register as calcined (sic) basalt or limestone, and hematite or hematitic basalt. Without additional information, the basalt and basalt talus might be interpreted as basalt, limestone, or perhaps an iron deposit. Admittedly, experience in working with color composites and deduction on the part of the geologist would decrease the likelihood of making such gross errors in identification.

Alluvium I, Figure 2(d) - This classification is difficult to evaluate because of the near impossibility of mapping small scattered areas of thin alluvial material resting on bedrock and the necessarily indefinite nature of contacts between alluvium and bedrock across undissected areas of low gradients. Apparently, only slope wash deposits (Qsf) are included in this multispectral classification.

The material classified as alluvium (Qal) in the north 1/2 of "section" one roughly coincides with the limestone classification shown in Figure 2(f). The slope wash deposits in the south 1/2 of "section" 2 are not classified. In "section" 3 only an insignificant fraction of the alluvium in the south 1/2 is registered. The Qal in the south 1/2 of "section" 4 is well classified but the large adjoining area of slope wash was not classified at all. The classification of slope wash in "section" 5, 6, 7, and 8 is moderately good. However, in the north 1/2 of "section" 7 extensive Qsf deposits are registered only by small fragmental areas. In "section" 8 the classification of Qsf is moderately good; adjoining terrace and wash deposits are not classified.

The classification of slope wash deposits in "sections" 9, 10, 11, 12 and 13 is moderately good with the following exceptions: (1) extensive deposits in the east 1/3 of "section" 9, and similiarly along the north-south boundary between "sections" 11 and 12, are but poorly classified by many small scattered areas. In "sections" 14, 15 and 16 large areas shown on the geologic map as Qsf are unclassified. Here the multispectral data probably could not discriminate between alluvium and the adjoining bedrock source areas.

Sandstone Conglomerate, Figure 2(e) - This bedrock formation is a distinctive reddish-brown colored sandstone that is conglomeratic in places and dips steeply eastward. It is well exposed in the north 1/2 of "sections" 6 and 7 and does not occur elsewhere in the test area. The sandstone is well-classified in "section" 7, but was missed entirely in "section" 6. Comparing Figures 2(d) and 2(e) it is obvious the sandstone recognition included much of the material classified as alluvium, especially south of the highway in "sections" 9, 10, 11 and 12.

Limestone, Figure 2(f) - A limestone bed, in contact with a few thin shale beds, crops out as a thin northwest-trending, steeply dipping bed only in the north 1/2 of "section" one. The representation of this thin bed is good. The scattered representation in other areas of the test site may be explained as calcareous coatings or caliche; verification would require field checking these areas.

Alluvium II, Figure 2(g) - Considering the entire test site the areas classified as alluvium, in general, have little relation to the alluvial areas shown on the geologic map. As an example, the large area of quartz monzonite outcrop in "sections" 15 and 16 is represented almost entirely as alluvium. In the west half of the test site large areas known to be alluvium and shown on the geologic map are very sparsely represented by the scattered patternless classification.

Basalt II, Figure 2(h) - Apparently this classification is for hematitic basalt, and cannot be evaluated in the area of the flow since the field mapping did not differentiate variations in composition or variation in degree of chemical weathering. The scattered areas classified as basalt south of the highway are not verified by the field mapping.

Granite III, Figure 2(i) - The rock classified as granite in Figure 2(i) are beyond the east-west boundaries of the test area and cannot readily be verified. They appear to be differentiating parts of larger granitic outcrops.

Alluvium III, Figure 2(j) - The classification depicted on this strip map apparently attempts to classify recent terrace deposits (Qty) along the main channel of the wash in the northwest part of the test area. These deposits are perhaps more complexly distributed than can be detailed on a geologic map. However, comparing the classification with the geologic map it is considered moderately good in "sections" 5, 6, 7, and 8. The classification in "sections" 9 and 10 may be correct although no Qty is shown on the map. The classification in "section" 12 is incorrect.

Granite IV, Figure 2(k) - The material classified as granite in "sections" 1, 5, 6(NE 1/4), 7, and 8 are incorrect; that in the northwest 1/4 of 6 is poor. In "Sections" 9 and 10 the areas classified as granite are actually Precambrian gneiss and is rather closely duplicated by the granite classified in Figure 2(a). The granite representation in "sections" 12 and 13 is very poor.

Granite V, Figure 2(l) - It is not at all clear what granitic material is being classified in this strip map. There is no granite in "section" 9. In "section" 13 the material classified as granite is within a much larger area of quartz monzonite.

Alluvium IV, Figure 2(m) - This classification best defines the Qal wash deposits, but is a very inadequate representation of the slope wash deposits. The alluvium in the north 1/2 of "sections" 1 and 2 is confined to narrow channels and the scattered classification is poor. In "sections" 3 and 4 alluvium is classified on the basalt flow and not likely to be correct. Wash deposits in the north 1/2 of "sections" 5, 6, 7, and 8 were not classified. South of the highway the extensive slope wash deposits are best classified in "sections" 13 an 14, but in general they are very poorly defined by the thinly scattered representation.

RAGAL Classification Based on Laboratory Ratio Values

This classification of three basalt types is shown on three strip maps in the ERIM report as Figure 3. This same figure was reproduced and presented in this report also as Figure 3. Because of the small scale they cannot be compared with any great accuracy to the geologic map. Further, as noted previously, the geologic mapping made no attempt to differentiate the basalt types (hematite, calcined-coated basalt, and unweathered basalt) classified by RAGAL. However, the gross misidentification (large area in southeast part of Figure 3(b) of quartz monzonite and slope wash deposits for calcine-coated basalt is readily evaluated as incorrect.

RAGAL Classification Based on In-scene Training Sets

The classification of four materials by this method is given in the ERIM report as Figure 4, and is reproduced and presented herein also as Figure 4. Our evaluation of the classifications has the same limitations set forth in the previous paragraph. The unweathered basalt shown north of the highway in Figure 4(b) is moderately good; all of the basalt shown south of the highway is incorrectly classified. The limestone as depicted in Figure 4(d) correctly defines the outcrop ("section" 1 on geologic map). Elsewhere the material registered as limestone is either calcareous material other than limestone such as coatings on basalt, caliche, or non-calcareous material incorrectly classified.

Color Composite

For geologists and engineers accustomed to working with aerial photographs the first viewing of a color composite will almost surely be disconcerting. The subtle blending of colors and variations in color tonal density, the absence of topographic relief, vegetation and outcrop patterns, and clearly imaged cultural features contribute to this first reaction. Knowledge of the color code and continued viewing alleviate to some extent this initial impression.

The basalt flow in "sections" 2-7 is the most striking representation on the composite. Three variations within the flow are represented - hematitic basalt, calcined basalt, and fresh basalt. Most of the flow and basalt talus are classified as calcined basalt (sic). Presumably the fresh basalt was differentiated on the basis of a composition sufficiently unique to separate it from the rest of the flow that is implied to be weathered. There is no reason to believe the fresh basalt was not calcined as was the other lave in the flow. The sensor recognition and processing technique that separated the fresh basalt from calcined basalt is not understood. None of these three calssifications were verified by the field study.

Quartz monzonite that is almost continuously exposed on the steep slopes below the flow in "sections" 1, 2, 3 and 4 is not classified; presumably the basalt talus on these slopes masks the quartz monzonite. The larger areal representation of fresh basalt (white) in the west 1/2 of "section" 4 and in sections 5 and 6 is difficult to explain. In the southeast 1/4 of "section" 7 the two isolated outcrops of "fresh" basalt are very well defined by the classification. In the north 1/2 of "section" one a northwest trending limestone bed and a basic dike are well-classified. In this same "section" large exposures of Precambrian gneiss and quartz monzonite are not distinguished. In the north 1/2 of "section" 6 a large prominent exposure of quartz monzonite appears to be classified as fresh basalt. In the north 1/2 of "section" 7 the Tertiary sandstone formation is distinguished from adjoining materials but the distinguishing color (yellow-green) may also represent leuco-granite and probably young alluvium. The large block of Precambrian gneiss in the north

1/2 of "sections" 7 and 8 is poorly classified; without prior knowledge the part in "section" 7 would probably be mistaken for fresh and hematized (sic) basalt. South of the highway in "sections" 9 and 10 Precambrian gneiss is well classified. Eastward from the east 1/2 of "section" 10 the extensive outcrops of quartz monzonite are obscure and not distinguishable from slope wash deposits. The problem of distinguishing erosional debris from an adjacent outcrop was discussed previously. Recent stream channel deposits are generally well-classified. Slope wash deposits are best classified in the west half of the study area. A small isolated basalt outcrop at the south boundary of "section" 12 is distinctly classified from the surrounding material.

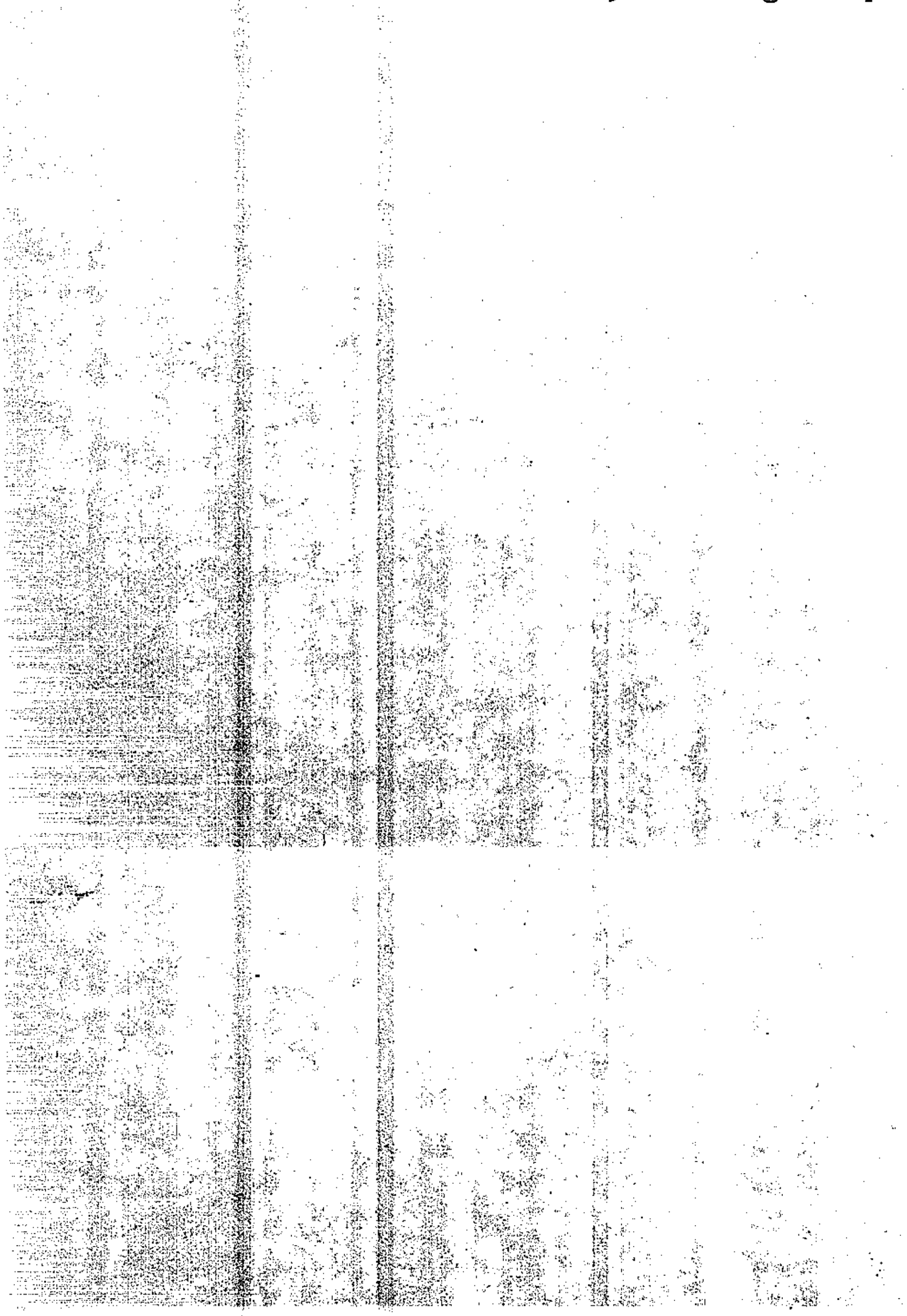
The large rectangular area in the southeast 1/4 of "section" 13 includes basic intrusive rock but not so large an area as shown by the basalt classification. The masking effect of increasing vegetation is very apparent in "sections" 14, 15, and 16, and with the exception of alluvium in the more prominent stream channels the classification is not clear.

Discussion

The classification of earth materials by remotely sensed multispectral data, at its present stage of development, cannot differentiate the various rock types, or delineate their areas of outcrop or deposition with sufficient accuracy to enable planning and engineering personnel to make route selections. The masking of ground truth by vegetation limits possible use of the method to areas most accessible and amenable to rapid field mapping by conventional methods. High mountainous areas, above the timber line, are not frequently considered for transportation routes. The representation of different rock types, (Table 1), by the same color on the composite is strongly disadvantageous from the practical point of view, for example that of the geologist and materials engineer. Detailed knowledge of the topography is fundamental to route selection and this information is obtained from ground-controlled aerial photography. It is not foreseen that remotely sensed multiband data will have the capability for accurate terrain representation in the near future.

The above evaluation purposefully emphasizes the negative aspects of the multispectral method, at its present state of development, for transportation planning and route selection. This critique should in no manner deter ongoing or future efforts to further develop and refine this experimental technique to the stage of practical application.

FIGURE 5 - Geologic Map



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ADDENDUM

A nontechnical description of the minimum changes or new developments that must be made before the multispectral techniques can be considered a useful and practical tool for general transportation route planning is given below:

1. Accurate classification of earth materials in areas having a moderately dense vegetative cover.

2. Capability to discriminate between aluvium and the parent bedrock.

3. Clear distinction between alluvium, sedimentary and igneous rocks.

4. Mask or eliminate the representation of compositional changes within a rock unit that are not important to the engineering properties, for example, hematitic basalt or calcined basalt.

5. Differentiation between weathered and fresh rock of the same composition by a change in hue rather than by strongly contrasting different colors.

6. Representation of rocks that vary widely in composition by strongly contrasting colors.

7. Eliminate or mask the representatiion of minerals that have little or no engineering significance, or are ubiquitous in various rock types. Examples are pyrite, quartz, limonite, and geothite. This will clarity the composite color representation.